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A COMPARATIVE STUDY OF THE LOWER CRETACEOUS FORMATIONS AND FAUNAS OF THE UNITED STATES.[1]

INTRODUCTION.

BESIDES the facts of wide distribution and economic importance the Cretaceous is notable for the problems of more purely scientific nature than it presents. For example, near the middle of Cretaceous time or at the beginning of the neo-Cretaceous (to adopt William's term) there was a great transgression of the sea upon the land—perhaps the greatest and certainly one of the most clearly recorded extensive one in geologic history. During the Trias and Jura almost all the present area of the continent was above sea level, as is shown by the absence of marine strata of those periods, excepting in limited areas of the Rocky Mountain and Sierra Nevada regions. The advance of the sea commenced with the Cretaceous, covering nearly all of Mexico and extending northward in the United States to southern Kansas, besides encroaching on the coast range region in the West while the lower Cretaceous sediments were forming. Then there was a greater and more rapid advance until at its maximum extent the sea covered almost the entire area between the Mississippi River and the Wasatch range, extending northward to the Arctic Circle. It also washed the western slope of the Sierra Nevada and covered the entire coastal plain of the Atlantic and the Gulf. The advance was not continuous nor constant, however. There were retrograde movements so that locally fresh-water and brackish-water deposits with associated coal beds are interstratified with the marine formations. Before the close of the Cretaceous while the Laramie beds were being

[1] Thesis submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Columbian University, Washington, D. C., June 1897.

laid down the sea had retreated from most of the continental area and it has never since invaded it beyond the coastal border regions. It is a noteworthy fact, as Neumayr[1] and others have pointed out, that there was a similar invasion of the sea upon the other continents in mid-Cretaceous time.

The occurrence of contemporary marine, fresh-water and brackish-water formations has greatly complicated the classification and correlation of the Cretaceous beds. Deposits formed under such diverse conditions naturally have few features in common, either lithologically or paleontologically, and their correlation must usually depend on similarity of stratigraphic and structural relations with formations of known age. In a few cases, however, the same flora and other land organisms have been preserved in both marine and fresh-water beds, and have thus demonstrated their practical contemporaneity.

Besides the sharp contrasts between marine and non-marine beds there are several distinct facies within the marine Cretaceous formations. Whether the paleontological differences are due to climate, to isolation, to differences in depth or in the nature of the sea bottom, are questions that should be solved independently in each case, but their solution is usually difficult. The first essential is to determine that the formations compared are actually contemporaneous or homotaxial. A failure to do this has led to serious errors in the past. For example, Roemer[2] noticed that the Cretaceous fauna of New Jersey is very different from that found in Texas in beds that he supposed to be contemporaneous. He also noticed that the former corresponded rather closely with the Cretaceous fauna of northwestern Germany, while the Texan fauna found its nearest analogues in the Cretaceous of southern Europe bordering on the Mediterranean. He concluded, therefore, from these geographic relations that the faunal differences were due mainly to climate, that the present climatal zones were already established in Cretaceous time and even that the ocean currents had

[1] Erdgeschichte, Bd. 2, p. 377.

[2] Am. Jour., Sci. 2d. ser., Vol. II, 1846, p. 364. Kreideb. v. Texas, 1852, p. 25.

approximately their present positions, since the European localities are respectively several degrees farther north than their American analogues, corresponding to the position of isothermal lines on opposite sides of the Atlantic at the present time. This was one of the first attempts to establish climatal zones at such an early period, as it was published even before von Buch's[1] generalization that the absence of Cretaceous faunas in the polar regions is due to the climatic conditions of that period. In Neumayr's studies of Mesozoic climates use was made of the difference between the Cretaceous faunas of New Jersey and Texas, and it has recently been cited by Kayser[2] and by J. Perrin Smith.[3] There is some evidence of the existence of climatal zones in the Cretaceous and even earlier in Mesozoic time, but Roemer's original examples should no longer be cited as proof, for it is now known that the faunas Roemer compared were not contemporaneous, the base of the marine Cretaceous beds in New Jersey being somewhat newer than the uppermost horizon that furnished the fossils he described from Texas. If he had made his comparisons with the Ripley fauna, which occurs near the top of the Texan Cretaceous and only a few miles east of the beds studied by him, Roemer's conclusion would probably have been very different, for a very large percentage of the species are identical with the New Jersey forms, and there is nothing suggestive of a warmer climate.[4] The Upper Cretaceous faunas of the Atlantic and Gulf border regions, when comparison is made with strictly homotaxial zones, are remarkably uniform along the whole coast from Texas to New Jersey.

The correlated faunas of the Rocky Mountain region and the great Plains show much greater differences when compared with the faunas just mentioned, and these may reasonably be

[1] Verbreitung und Grenzen d. Kreidebildungen. Verhandl. des Naturhist. Vereins d. Preuss. Rheinlande u. Westphalien, Bd. 7, pp. 211–242.

[2] Text-book of Comparative Geology, translated by Lake, p. 283, Lond., 1893.

[3] JOUR. of GEOL., Vol. III, p. 485, Chicago, 1895.

[4] See WHITFIELD; Bull. Am. Mus. Nat. Hist., Vol. II, 1889, pp. 113–116 and WHITE, Bull. U. S. Geol. Surv., No. 82, pp. 84, 111.

attributed in part to the influence of climate, but it would carry us too far from our subject to discuss this question fully.

The life of the Cretaceous period offers many other points of general interest, chief among which is the fact that while it is essentially Mesozoic in character, and is thus allied with the life of earlier periods, it nevertheless includes the earliest recorded repres ntatives of very many recent generic and family types and some groups of higher rank, and in the later stages this modern element is often relatively large. This statement refers chiefly to plants and invertebrates, for, with the exception of the Teleost fishes, which are introduced for the first time, the vertebrates nearly all belong to types now extinct or of relatively little importance. So far as the record goes the great group of placental mammals was not yet introduced, and the vertebrate fauna consists largely of Mesozoic types of reptiles, such as dinosaurs, pterosaurs and pythonomorphs, with a few small mammals of the lowest groups, and birds of archaic types.

Among the invertebrates the Ammonoidea are very greatly differentiated and finally become extinct with the close of the period. Many other forms, such as Inoceramus, certain types of Ostreidae, Nerinea, Anchura, Pugnellus, etc., do not pass the upper limits of the Cretaceous. On the other hand, the Ostreidae, Anomiidae, Mytilidae, Unionidae, Veneridae, Mactridae, Turritellidae, Naticidae, Volutidae, etc., are represented by forms closely related to living species. The flora is completely revolutionized and modernized during the Cretaceous. Early in the Cretaceous the first Dicotyledons occur and by mid-Cretaceous time they largely predominate and numerous genera of trees that time still live in our forests are already introduced, so that the biologist who is studying recent species must often go back to the Cretaceous faunas and floras to complete his data for a rational classification.

RECOGNITION OF THE LOWER CRETACEOUS IN THE UNITED STATES.

Before going farther it may be well to recall the general classification of Cretaceous deposits as adopted in Europe. It is

now customary to recognize only two principal divisions — Lower Cretaceous and Upper Cretaceous — instead of three as formerly. The number and nomenclature of the subdivisions varies in different countries and with different authors, but the terms Neocomian, Urgonian, Aptian, Albian, Cenomanian, Turonian, Senonian and Danian proposed by d'Orbigny are frequently used and universally understood.

In Neumayr's *Erdgeschichte*[1] the following arrangement is adopted:

Upper Cretaceous.	Lower Cretaceous.
Senonian.	Gault.
Turonian.	Aptian.
Cenomanian.	Neocomian.

In this classification of the Lower Cretaceous the Wealden is treated as simply a non-marine facies of the Neocomian, the Urgonian is made a subdivision of the Neocomian (as it was by d'Orbigny also) and the English name Gault is substituted for Albian. Some authors place the Gault in the Upper Cretaceous, but for comparison with American formations it is more satisfactory to classify it with the older beds.

These minor subdivisions are not applicable to the American Cretaceous excepting in the most general way, and, as Dr. White has insisted, it is not probable even that the corresponding principal divisions as recognized on the two continents are strictly homotaxial, but the accumulating evidence tends to show that the difference is not very great. In making an independent and natural classification of our formations we have perhaps placed a few beds in the Lower Cretaceous that by European standards would go in the Upper Cretaceous.

The first definite recognition of Lower Cretaceous in this country based on good evidence was by Professor Jules Marcou,[2] who in 1855 identified a number of fossils from Texas as Neocomian, and asserted that rocks of that age cover considerable

[1] Bd. 2, p. 344.

[2] Pacific R. R. Reports, 8vo edition, Vol. IV, pp. 40–48, 1855; republished in 4to edition and in Geology of North America.

areas in Texas and Indian territory. Marcou has maintained the correctness of his determination in numerous subsequent papers, but for various reasons his opinion, though essentially correct, did not meet with general acceptance for many years. The principal causes that conspired to prolong this misconception were (1) Marcou's own error in referring to the Jurassic certain New Mexican exposures of a part of the same series; (2) Roemer's previously published important work, "Die Kriedebildungen von Texas," in which on paleontological grounds all the Texan Cretaceous beds were referred to the Upper Cretaceous;[1] (3) the publication of Shumard's[2] section in which the stratigraphic succession is very erroneously given, and (4) the fact that the investigation of other regions in the United States did not reveal any Lower Cretaceous beds that were really comparable with those of Texas. The subject remained thus until 1887 when the publication of papers by Dr. C. A. White[3] and Mr. R. T. Hill,[4] based on the latter's field work, established the fact that there is in Texas a great series of Cretaceous rocks underlying the generally recognized Upper Cretaceous of other parts of the country. This is the Comanche series that has since become so familiar through the numerous papers of Mr. Hill.

[1] The idea has been current for some years that ROEMER'S principal error was a stratigraphic one in placing his "Cretaceous of the Highlands" above the "Cretaceous at the foot of the Highlands" as he did tentatively in his earlier work "Texas," but a careful perusal of the introductory pages — especially page 19 — of the "Kreibildungen" will show that he did not finally attempt to establish any stratigraphic succession, and that he admitted that there were both paleontologic and physical reasons for regarding the beds of the Highlands as older than the others, and he suggested that their topographically higher position might have been caused by a fault. His real error was that in his paleontological comparisons with the Cretaceous of southern Europe, he did not recognize the now well-known fact that there are two distinct horizons, one in the Upper Cretaceous and the other in the Lower, each characterized by peculiar species of Rudistae, Chamidae, etc.

[2] Trans. Acad. Sci., St. Louis, Vol. I, pp. 582–589, 1856–1860.

[3] On the Cretaceous formations of Texas and their relations to those of other parts of North America. Proc. Phila. Acad. Nat. Sci., 1887, pp. 39–47.

[4] The topography and geology of the Cross Timbers and surrounding regions in northern Texas. Am. Jour. Sci., 3d ser., Vol. XXXIII, pp. 291–303, pl. 6. The Texas section of the American Cretaceous. Am. Jour. Sci., 3d ser., Vol. XXXIV, 1887, pp. 287–319.

Some years before the investigation of the Texan Cretaceous was begun several geologists described strata in Virginia, Maryland, Delaware, and New Jersey that are now usually referred to the Potomac formation, but they had few facts on which to base their age determination. Thus W. B. Rogers[1] described these beds as Upper Secondary, and provisionally referred them to the Upper Jurassic, though he later[2] suggested that they might form a "passage-group analogous to the Wealden of British geology." Tyson[3] also described a part of the same series under the designation of "iron ore clays" which he at first referred to the Cretaceous, but afterward[4] placed "at least as low as the Oolitic." According to Dawson[5] and Fontaine[6] Tyson considered that these beds belonged to the Wealden, but he seems not to have published that opinion. In 1886 Mr. W J McGee[7] named and described the Potomac as a distinct formation including the above mentioned beds that had been discussed by Rogers and Tyson. Its determination as of Lower Cretaceous age has been mainly due to the paleobotanical work of Professors L. F. Ward[8] and W. M. Fontaine.[9]

In 1869 Gabb and Whitney[10] defined the Shasta group of California, stating that "It contains fossils seemingly representing ages from the Gault to the Neocomian, inclusive." The Shasta group has ever since been referred to the Lower Cretaceous, and subsequent investigations have only confirmed the

[1] Report of Prog. of Geol. Surv. of Va. for 1840, Richmond, 1841. Idem for 1841, Richmond, 1842. Both reprinted in Geology of the Virginias, 1884, pp. 413–546.

[2] Proc. Bost. Soc. Nat. Hist., Vol. XVIII, 1875, p. 105.

[3] First Rept. State Agricultural Chemist of Md., pp. 41–43, Annapolis, 1860.

[4] Second Rept. State. Agri. Chemist, p. 54, Annapolis, 1862.

[5] Trans. Roy. Soc. Canada, Vol. III, 1885, sec. 4, p. 18.

[6] Monograph U. S. Geol. Surv., No. 15, p. 5.

[7] Rept. of Health Officer for the Dist. of Columbia for 1885, pp. 23–25; Am. Jour. Sci., 3d ser., Vol. XXXV, 1888, pp. 120–143.

[8] Am. Jour. Sci., 3d ser., Vol. XXXVI, 1888, pp. 119–131.

[9] Monograph 15, U. S. Geol. Surv., 1889. See also many subsequent articles by both authors and by McGee, Darton, White, Marsh, and Clark listed in the accompany bibliography.

[10] Palæont. of California, Vol. II, p. xiv.

original suggestion as to its age. The stratigraphy and paleontology of the Shasta beds have been described or discussed by Gabb, Becker, White, Diller, Turner, Fairbanks, and Stanton.

Soon after the definition of the Shasta, Richardson[1] described strata in the Queen Charlotte Islands that were recognized by Billings from the invertebrate fossils as in part the equivalent of the Shasta, and on the evidence of a few plants were assigned to either the Jurassic or the Lower Cretaceous by Dawson. The fauna of these beds and of their equivalents on the mainland of British Columbia has since been described by Whiteaves, who regards them as not later than the Gault.

A few years later a series of fresh-water coal-bearing beds, the Kootanie formation, in the Rocky Mountain region of southern Canada, was recognized and defined by Dr. Geo. M. Dawson. The accompanying flora was studied by Sir William Dawson, who determined its age to be Lower Cretaceous and published the first account[2] of the formation in connection with the description of the flora. In 1887, the coal-bearing rocks of Great Falls, Mont., were referred to the Kootanie by Professor J. S. Newberry,[3] who later discussed the flora more fully and pointed out its close relationship with the flora of the Potomac. The possible occurrence of beds of the same age in the Black Hills, South Dakota, has been shown by Professor L. F. Ward[4] on the evidence of cycads and a few other plants of Lower Cretaceous aspect in beds that have formerly been referred to the Dakota.

Before this time and soon after the Potomac formation became known, Smith and Johnson[5] had described the Tuscaloosa formation in Alabama. It is now correlated with the upper portion of the Potomac or the Raritan beds.

[1] Geol. Surv. of Canada, Rept. of Progress for 1872–3, pp. 32–65.

[2] Science, Vol. V, 1885, p. 31; Trans. Roy. Soc. Canada, Vol. III, 1885, sec. 4, pp. 1–22; idem, Vol. X, 1892, sec. 4, pp. 79–93.

[3] School of Mines Quarterly, Vol. VIII, 1887, pp. 327–330; Am. Jour. Sci., 3d ser., Vol. XLI, 1891, pp. 191–201.

[4] JOUR. GEOL., Vol. II, 1894, pp. 250–266.

[5] Bull. U. S. Geol. Surv., No. 43, 1887, p. 95.

From this review it is seen that the Lower Cretaceous formations now known in the United States are the Comanche series of the Texan region, the Shasta group (including Knoxville and Horsetown beds) of the Pacific Coast, the Kootanie of Montana and possibly of the Black Hills, the Potomac of the Atlantic coastal plain, and the Tuscaloosa of the Gulf border. Only the first two are marine formations. In our comparisons of these formations it will not be necessary to enter into minute details of stratigraphy and lithology, since the most general descriptions will show that in most cases we have to deal with contrasts rather than with resemblances. This is true not only when the marine beds are compared with the non-marine, but also when the two marine formations are compared with each other, or the Potomac is compared with the Kootanie. In the descriptions that follow, mainly summarized from the latest published accounts, the principal characteristics of each formation are given, beginning with the fresh-water beds. The statements concerning the invertebrate faunas embody more of the results of my own studies.

GEOLOGIC DESCRIPTION OF THE FORMATIONS.

The Potomac formation.—This term was originally applied by McGee to certain non-marine beds in Maryland, the District of Columbia, and Virginia, resting against the old crystalline rocks of the Piedmont region, and unconformably overlain by marine Upper Cretaceous deposits. The Potomac as thus defined is composed of irregular deposits of variegated clays, sand, arkose, pebbles, and bowlders, with local lenses of iron ore and lignitic seams. The sand and arkose are sometimes indurated, but frequently are unconsolidated deposits. In general, the arenaceous deposits seem to predominate in the lower part of the series and argillaceous beds in the upper, though no single stratum retains the same lithologic character over any considerable area. The estimates of thickness vary from 500 or 600 feet (McGee) to 1175 feet (Ward). Professor Ward,[1] who has

[1] See 15th Ann. Rept. U. S. Geol. Surv., pp. 313–397, and 16th idem, pp. 469–540.

studied the stratigraphy and the flora of the Potomac in great detail, retains under that name all the strata originally included in it, and also makes it comprise all the beds that have been named the Raritan formation, extending from Maryland across Delaware and New Jersey to the islands off the southern coast of New England. That is, he makes it coextensive with Dr. White's[1] non-marine division of the Cretaceous of the Atlantic border region which was believed to consist of two distinct formations, separated by a time interval that marked the distinction between Lower and Upper Cretaceous. Though assigning these beds all to a single formation Professor Ward recognizes in it six distinct "series," as follows:

Potomac
6. Albirupean [in part equivalent to Raritan].
5. Iron Ore,
4. Aquia Creek,
3. Mount Vernon,
2. Rappahannock,
1. James River.

Each of these divisions, excepting No. 5, is, according to the author cited, characterized by a distinct florula altogether constituting a flora of from 800 to 1000 species. Detailed discussions and comparisons of this flora are contained in the articles above referred to in the fifteenth and sixteenth annual reports of the U. S. Geol. Survey. From these it appears that while the whole formation is referred to the Lower Cretaceous the flora of the lower beds, in which the earliest known dicotyledons appear, has Jurassic affinities, and is related to the Wealden flora. There is a progressive change, the modern types predominating more and more until in the uppermost beds (No. 6) the plants show a marked affinity to the Upper Cretaceous Cenomanian flora. An interesting comparison of the Potomac flora with the Lower Cretaceous flora of Portugal, shows that while they have but few species in common the general characters of the two floras are very similar, and as Professor Ward remarks, "the lower Cretaceous flora of Portugal is, botanically speaking, a very close repetition of that of America." This fact is in interesting agreement

[1] Bull. U. S. Geol. Surv., No. 82, pp. 74–100.

with other independent sources of evidence, for the Portuguese plant beds are interstratified with strata carrying marine faunas that are, as we shall see, closely related to the fauna of the Comanche series, and one of the lower horizons in the Comanche has yielded fossil plants closely connected with the flora of the lower Potomac.

Invertebrate fossils are remarkably scarce in the Potomac, and the few that have been found do not afford any definite evidence as to the age of the beds. The only mollusks known from the lower horizons developed in Maryland and Virginia, are a few internal casts apparently belonging to small simple forms of Unio, whose only geological value is to show the fresh-water origin of the beds. In New Jersey, besides some Unios that probably came from a much later formation, five species of mollusks have been reported from the Raritan formation.[1] They have been referred to Astarte, Corbicula, Gnathodon, and Ambonicardia (gen. nov.), but not one of them is well enough preserved to show generic characters, and in invertebrate paleontology, at least, age determinations, based on new species of doubtful genera, are worthless.

Vertebrate fossils have been collected from the Lower Potomac in a limited area between Washington and Baltimore. One species based on a tooth, *Astrodon Johnsoni*, has been described by Dr. Leidy, and Professor Marsh[2] has named five others: *Pleurocoelus nanus*, *P. altus*, *Priconodon crassus*, *Allosaurus medius*, and *Coelurus medius*. He states that associated with these there are remains of crocodiles and tortoises, of Jurassic types, some fishes and a few mollusks. Also that "The fossils here described, and others from the same horizon seem to prove conclusively that the Potomac formation in its typical localities in Maryland is of Jurassic age and lacustrine origin." The genera Allosaurus and Coelurus were originally described from the Atlantosaurus beds (Jurassic) of the Rocky Mountain region, and Pleurocoelus has since been found in the same beds repre-

[1] Monograph 9, U. S. Geol. Surv., pp. 22–28.

[2] Am. Jour. Sci., 3d. ser. Vol. XXXV, 1888, pp. 89–94.

sented by a Potomac species. According to Lydekker Pleurocoelus also occurs in the Wealden of England. In recent papers Professor Marsh[1] has attempted to establish the Jurassic age of the whole Potomac formation in its broadest sense. He correlates it by the relationship of the vertebrate faunas on the one hand with the Atlantosaurus beds, and on the other with the European Wealden, asserting that they are homotaxial equivalents. Assuming that the Atlantosaurus beds are Jurassic, it consequently follows, according to his reasoning, that the Wealden and the Potomac are also Jurassic. But even admitting that the vertebrate faunas are so closely related as to establish the equivalence of the deposits in these three widely separated regions, the correlation can apply only to the beds in which the fossils occur, and in the Potomac they have so far been found only in the lower portion. Recent stratigraphic studies by Professor W. B. Clark and Mr. Arthur Bibbins on the Potomac in Maryland, have an important bearing on this question. A preliminary statement of their results, including a new classification of the deposits, was published[2] some months ago, and a more detailed account has been issued since the present paper was first written.[3] Their most important results are summarized as follows:

"It is the conclusion of the authors, founded upon a detailed stratigraphic study of the Potomac group, that all the beds which have afforded dicotyledonous types of plant life are above those from which Professor Marsh has obtained vertebrate remains, and moreover, that a marked unconformity exists between the two series of deposits.

"The several formations into which the larger unit of the Potomac group has been divided, are as follows:

[1] Am. Jour. Sci., 4th ser., Vol. II, 1896, pp. 295–298, 375–377, 433–447. See also articles on the same subject by HOLLICK, WARD, HILL, and GILBERT, Science, Vols. IV and V, 1896, 1897.

[2] Physical Features of Maryland; Maryland Geol. Surv., Vol. I, Pt. 3, pp. 56–59, April 1897.

[3] JOUR. GEOL., Vol. V, pp. 479–506, July–Aug. 1897.

Lower Cretaceous	Raritan Formation		Potomac.
	Patapsco	"	
Upper Jurassic (?)	Arundel	"	Group"
	Patuxent	"	

According to these authors all of the Potomac vertebrates that have been recorded have come from the Arundel formation, while practically the whole of the Potomac flora occurs in higher horizons above the principal unconformity which separates the Patapsco from the Arundel. All of Professor Ward's plant-bearing "series" below the Albirupean are believed to be local subdivisions and variations of the Patapsco formation. The underlying beds are doubtfully assigned to the Upper Jurassic on the authority of Professor Marsh's determination of the affinities of the vertebrates. It has been shown, however, that his comparisons are chiefly with the Wealden fauna, and if the difficult stratigraphy of the Potomac has now been correctly determined the evidence tends to prove the post-Wealden age of the principal plant-bearing horizons.

There have long been differences of opinion as to the age of the Wealden, and it may well be that it is partly Jurassic, but its constantly close association with the Cretaceous, and the fact that where it is present the lowest marine beds of the Neocomian are always absent, are strong arguments for regarding it as a non-marine facies of the Neocomian. If all the Wealden deposits are transferred from the Cretaceous to the Jurassic because the dinosaurs are closely related to those of the Jurassic, then we know practically nothing of the land fauna of the Lower Cretaceous, and no one can say whether the dinosaurs that must have lived in early Cretaceous time, were very different from those of the Jurassic or not. Professor Marsh's statements may be fairly interpreted to mean that the age of the Atlantosaurus beds is dependent on that of the Wealden, and if the latter is Cretaceous the former are also. There is nothing in the stratigraphic relations of the Atlantosaurus beds that would prevent their reference to the Lower Cretaceous, for they are everywhere immediately overlain by Upper Cretaceous strata.[6] How-

[6] There is a possible exception to this in the Black Hills of South Dakota, where

ever these questions may be finally decided, it is evident that the discussion as to the Potomac formation is not so much on its correlation with deposits elsewhere as on the more general question of the upper limits of the Jurassic.

The Tuscaloosa formation.—The beds known under this name have their principal development in Alabama, extending thence eastward into Georgia and westward into Mississippi. According to Prof. E. A. Smith[1] the formation consists of "heavy bedded purple and mottled and gray clays in the lower parts, alternating with more distinctly stratified clays containing an abundance of plant remains, chiefly in the form of leaf impressions. Above these clayey beds are sands of various colors, white, yellow, gray, pink, and purple, usually micaceous and strongly cross-bedded. In many places irregular pockets of small angular chert pebbles are interbedded with the sands, but these pebble beds make only a very small proportion of the strata. In places also beds of dark red and mottled clay occur in the upper part of the formation." In the eastern part of the area it rests on ancient crystalline rocks while farther west it laps up on the Paleozoic sediments. The overlying beds are of Upper Cretaceous age.

The thickness of the Tuscaloosa is estimated at 1000 feet.

Lithologically and stratigraphically the Tuscaloosa is seen to correspond closely with the Potomac and the evidence of the flora leads to the same correlation. Professor Smith[2] publishes a list of 35 species of fossil plants determined by Professor Ward, who compares them with the Amboy Clay (*i. e.* Uppermost Potomac) flora. In later publications Professor Ward[3] definitely correlates the Tuscaloosa with the Amboy and Raritan clays, suggesting that possibly one of the older horizons of the Potomac may also be represented in Alabama. No animal remains

Professor Ward obtained plants that he regards as Lower Cretaceous, and the Atlantosaurus fauna has also been found in this same region, but what relation the plant-beds have to the vertebrate horizon, and whether the plants and vertebrates do not really occur in the same bed has not been determined.

[1] Rep. on Geol. of the Coastal Plain of Ala., pp. 307–308, Montgomery, 1894.

[2] *Ibid.*, p. 348.

[3] 15th Ann. Rept. U. S. Geol. Surv., pp. 337–338; 16th Ann. Rept., p. 470.

have been reported from these southern beds. According to Mr. N. H. Darton[1] the Potomac deposits are practically continuous along the whole Atlantic coastal plain until they connect with the Tuscaloosa. It is evident that conditions of deposition were remarkably uniform throughout this long coastal border region during Potomac time but the earlier part of the epoch is recorded by deposits now visible only in the middle portion of the area. The northern and southern ends either did not receive deposits until towards the close of the epoch or else the early deposits were overlapped and concealed by the later beds.

The Kootanie formation.— A somewhat detailed description of the typical area of the Kootanie is given by Dr. Geo. M. Dawson.[2] It is found in the Rocky Mountains of Canada between latitudes 49° and 51° 30′. The beds there have a total estimated thickness of over 7000 feet and consist chiefly of shales and sandstones of very varied texture and appearance, with beds of coal. The Canadian localities have yielded a flora[3] of about 27 species which show by identical and allied species a very close relationship with the Potomac. No animal remains have been reported excepting one imperfect specimen of a Goniobasis indicating fresh waters, and a fragment of a belemnite which was very probably derived from an older formation.

In the United States the Kootanie occurs at Great Falls, Montana, near which place a thick coal bed in the formation is mined. The section has been described by Mr. W. H. Weed[4] who states that the Kootanie "is a series of rapidly alternating sandstones and clay shales with few and thin beds of impure limestone. Individual beds are inconstant, the heavy ledges of heavy sandstone passing laterally into arenaceous clays and *vice versa*."

The top of the formation is not clearly defined but the thickness is evidently several hundred feet. About 38 species of fossil

[1] Bull. Geol., Soc. Am., Vol. VII, 1896, pp. 514–517.

[2] Rept. Geol. Surv. of Canada for 1885, Rept. B. A more general account in Am. Jour. Sci., 3d ser., Vol. XXXVIII, pp. 120–127.

[3] Trans. Roy. Soc. Canada, Vol. III, 1885, Sec. 4, pp. 1–10. Idem, Vol. X, 1892, Sec. 4, pp. 79–93. Idem, Vol. XI, 1893, Sec. 4, p. 11.

[4] Two Montana coal fields. Bull. Geol. Soc. Am., Vol. III, 1892, pp. 301–323.

plants have been listed or described from the Kootanie of this neighborhood by Professors Newberry[1] and Fontaine.[2] These show a close connection with the not distant Canadian Kootanie, and more than half of them (21 out of 38) have also been identified from the Potomac. It is noteworthy, however, that no dicotyledons have been found in the Kootanie, thus indicating that the higher horizons of the Potomac are possibly not represented there. Invertebrates are represented in the Great Falls area only by a few imperfect specimens of Unio. A higher bed which may belong to a later formation has yielded undescribed species of Neritina, Goniobasis, and Corbula (?).

It is evident that the Kootanie and Potomac were laid down in distinct basins of fresh and brackish waters and that the floras prove that they are in part homotaxial equivalents.

The Shasta group.— This general name was given by Gabb and Whitney to all the Lower Cretaceous rocks of California. In 1885 Dr. C. A. White[3] and Dr. G. F. Becker[4] named two subdivisions of the Shasta, the Knoxville and the Horsetown beds, that have since been generally recognized. Detailed sections have been described by Turner,[4] Diller[5] and the present writer[6] who has recently reviewed the geology of the Knoxville beds and described their fauna.

The Shasta is a marine formation distributed along the western side of the Sacramento valley and in the coast ranges of California, Oregon, and Washington. The lower divisions have been recognized as far north as latitude 35°.

"Dark clay shales greatly predominate over all other kinds of rocks in the Knoxville beds, but there is also considerable sandstone, usually in thin beds. In some places the lower part of the formation consists of alternations of shale and sandstone,

[1] Am. Jour. Sci., 3d ser., Vol. XLI, 1891, pp. 191–201.

[2] Proc. U. S. Nat. Museum, Vol. XV, 1892, pp. 487–495.

[3] Bull. U. S. Geol. Surv., Nos. 15 and 19.

[4] Bull. Geol. Soc. Am., Vol. II, 1891, pp. 303–314.

[5] Am. Jour. Sci., 3d ser., Vol. XL, 1890, pp. 476–478. Bull. Geol. Soc. Am., Vol. IV, 1893, pp. 205–224. Idem, Vol. V, pp. 435–464.

[6] Bull. U. S. Geol. Surv., No. 133, 1896.

or calcareous material, in bands only a few inches thick. There are also occasional thicker bands of sandstone, and sometimes massive conglomerates. The larger bodies of shale frequently contain many calcareous concretions, and such concretions are sometimes found even in the coarse conglomerates. More rarely there are larger bodies of limestone, several feet in thickness, but they do not form continuous beds of any great extent. The conglomerates also appear to be local deposits of no great length, though sometimes of very considerable thickness." The overlying Horsetown beds have essentially the same lithologic character and are distinguished mainly by marked differences in the fauna—especially by the absence of Aucella and the greater abundance and variety of the ammonites. Where the base of the Shasta has been observed it rests on metamorphic rocks of undetermined age. It is conformably overlain by the upper Cretaceous Chico formation which in its basal portion is probably as old as the Cenomanian.

The Lower Cretaceous has an enormous thickness at some localities on the Pacific coast. A section on Elder Creek, Tehama county, Cal., measured by Mr. Diller, showed about 20,000 feet of Knoxville and 6000 feet of Horsetown beds without any evidence of duplication of strata. This thickness is exceptional, though other localities in the same region show apparent thicknesses of 12,000 to 15,000 feet.

Although the Shasta group is of marine origin it has yielded a number of land plants from several different horizons ranging from the upper third of the Knoxville to near the top of the Horsetown beds. Professor Fontaine has recognized twenty-six different forms among them. He says that "all have their nearest relations in Lower Cretaceous forms, and there is no plant that would indicate an age different from Lower Cretaceous." A large proportion of the species occur in the Potomac and a few are found in the Kootanie and in the Comanche series, none of which offers any other means of direct comparison with the Shasta. Here, as in the Kootanie, no dicotyledons have been found.

In my recent work on the Knoxville fauna the following species are described:

Rhynchonella schucherti S.
R. whitneyi Gabb
Rhynchonella sp.
Terebratula sp.
Terebratula californica S.
Ostrea sp.
Anomia senescens S.
Spondylus fragilis S.
Lima multilineata S.
Pecten californicus Gabb?
Pecten sp.
Pecten complexicosta Gabb
Avicula whiteavesi S.
Aucella piochii Gabb
A. piochii var. ovata S.
A. crassicollis Keyserling
Inoceramus ovatus S.
Modiola major Gabb
Myoconcha americana S.
Pinna sp.
Arca textrina S.
Pectunculus? ovatus S.
Nucula gabbi S.
Nucula storrsi S.
Leda glabra S.
Cardiniopsis unioides S.
Solemya occidentalis S.
Astarte corrugata S.
Astarte californica S.
Astarte trapezoidalis S.
Opis californica S.
Lucina ovalis S.
L. colusaensis S.
Cyprina occidentalis Whiteaves
Solecurtus? dubius S.
Corbula? persulcata S.
Corbula filosa S.
Dentalium californicum S.
Helcion granulatus S.
Fissurella bipunctata S.
Pleurotomaria sp.
Turbo paskentaensis S.
T. wilburensis S.
T. trilineatus S.
T. colusaensis S.
T. morganensis S.
T.? humerosus S.
Amberleya dilleri S.
Atresius liratus Gabb
Turritella sp.
Hypsipleura? occidentalis S.
Hypsipleura gregaria S.
Cerithium paskentaensis S.
C. strigosum S.
Cerithium sp.
Aporrhais sp.
Phylloceras knoxvillense S.
Lytoceras batesi (Trask)
Desmoceras californicum S.
Desmoceras sp.
Olcostephanus mutabilis S.
O. trichotomus S.
Hoplites hyatti S.
H. storrsi S.
H. angulatus S.
H. crassiplicatus S.
H. dilleri S.
Perisphinctes sp.
Diptychoceras? sp.
Crioceras latus Gabb
Aptychus? knoxvillensis S.
Belemnites impressus Gabb
Belemites tehamaensis S.
Belemites sp.

To quote again from my previous paper: "When studying the Knoxville fauna as a whole, either in the field or from aver-

age collections, one is impressed with the excessive preponderance of the Aucellæ, so far as number of individuals is concerned. In many places they are so abundant that they must have actually monopolized the sea bottom, crowding out everything else.

"Considering the fauna as an assemblage of species, the proportion of brachiopoda, though there are so few, is somewhat greater than in other American Cretaceous faunas. Among the mollusca the variety of forms of Turbinidæ is noteworthy. The proportion of ammonoids is also quite large, and there is an unusual development of the genus Hoplites."

The Aucellæ do not pass above the Knoxville, or to speak more accurately, the top of the Knoxville is drawn at the upper limit of the Aucella beds. Several other Knoxville species, however, do pass up into the succeeding Horsetown fauna. This fauna has not yet been revised and a considerable number of undescribed species are known in recent collections, but the following lists, though incomplete, will give a correct idea of its general character. In the lower part of the Horsetown ammonites are locally very abundant, the genera Lytoceras and Phylloceras being especially well represented in individuals. The following species occur in this portion of the series:

Pentacrinus sp.
Rhynchonella sp.
Pecten operculiformis Gabb
Plicatula variata Gabb
Avicula whiteavesi Stanton
Inoceramus sp.
Nemodon vancouverensis (Meek)
Trigonia æquicostata Gabb
Trigonia leana Gabb ?
Opis sp.
Eriphyla sp.
Protocardia sp.
Pleuromya papyracea Gabb
Lunatia avellana Gabb
Potamides diadema Gabb
Helicaulax ? bicarinata Gabb
Actæon impressus Gabb
Lytoceras batesi (Trask)
Phylloceras onoense Stanton
Hoplites remondi (Gabb)
Olcostephanus traski (Gabb)
Desmoceras hoffmanni (Gabb)
Crioceras latus Gabb
Crioceras percostatus Gabb
Ancyloceras remondi Gabb
Helicancyclus æquicostatus Gabb
Diptychoceras lævis Gabb
Belemnites impressus Gabb

The few fossils that have been collected from the middle portion of the Horsetown do not show any decided change in

the fauna until the extreme upper beds are reached, when a more abundant fauna appears that shows a blending with the succeeding Upper Cretaceous Chico fauna. These upper Horsetown beds have yielded the following species:

Rhynchonella sp.
Exogyra parasitica Gabb
Pecten operculiformis Gabb
Mytilus quadratus Gabb
Mytilus cf. lanceolatus Sowerby
Cucullæa truncata Gabb
Nemodon vancouverensis (Meek)
Leda translucida Gabb
Trigonia æquicostata Gabb
Trigonia leana Gabb
Meekia sella Gabb
Meekia navis Gabb
Meekia radiata Gabb
Chione varians Gabb
Tellina matthewsonii Gabb
Mactra sp.
Pleuromya papyracea Gabb
Panopæa concentrica Gabb
Lunatia avellana Gabb
Liocium punctatum Gabb
Actæonina californica Gabb
Ringicula varia Gabb
Desmoceras hoffmanni (Gabb)
Desmoceras cf. beudanti (Brongniart)
Haploceras breweri (Gabb)
Lytoceras sacya Forbes
Schloenbachia inflata (Sowerby)
Acanthoceras cf. mammillare (Schloth.)
Belemnites sp.

After weighing the available paleontologic evidence and making all practicable comparisons with foreign Mesozoic fossils the conclusion was reached that the whole of the Knoxville is referable to the Neocomian and that the Horsetown includes all the rest of the Lower Cretaceous and possibly extends up into the Upper Cretaceous.

The abundance of Aucellæ gives the Knoxville fauna a decided boreal appearance, for the distribution of that genus has been considered essentially circumpolar. Some of the ammonitic types also point in the same direction, but the genera Lytoceras and Phylloceras are also represented, and these are the genera that Neumayr considered especially characteristic of the southern or tropical zone. With the disappearance of Aucella the fauna of the Horsetown becomes almost purely southern in type, so far as the ammonites are concerned, as Professor J. P. Smith[1] has stated; but this change can hardly be attributed to a change in climate, for it will be remembered that Aucella beds occur as

[1] Mesozoic Changes in the Faunal Geography of California, JOUR. GEOL., Vol. III, 1895, pp. 381–382.

far south as the Himalayas in India and almost to the tropics in Mexico. Besides, the fossil plants of both divisions of the Shasta, as well as those of the more northern Kootanie, indicate at least a warm temperate climate.[1] The facts seem to support Dr. Kossmat's[2] opinion that Neumayr exaggerated the influence of climate on the distribution of ammonites [and other Mesozoic invertebrates as well], and that the climatic influence was of little importance when compared with geographic relations, the presence or absence of opportunities for free communication, etc. Neumayr[3] himself referred the California Cretaceous to his Indo-Pacific region, and spoke of the persistent conservative character of the Mesozoic faunas of that region. The earliest Cretaceous deposits are apparently not preserved on the Asiatic side of the Pacific, but beginning with the Upper Cretaceous beds, usually classed as Cenomanian, on about the horizon of the uppermost Horsetown beds, very closely related faunas are widely distributed around the borders of the great Pacific basin. They occur in southern India, Japan, Saghalin, Queen Charlotte Islands, Vancouver, and, according to Steinmann,[4] on the west coast of Chile. While Lower Cretaceous deposits are not so widespread in that region, the character and distribution of their fauna down the west coast of North America seem to indicate that the Pacific was then the home of a uniform fauna, and that it was directly connected with the boreal sea that covered Russia and Siberia, but was not in communication with the Atlantic. This subject can be discussed more satisfactorily after reviewing the Cretaceous of the Texas region.

The Comanche series.— In area and in faunas the greatest development of the Lower Cretaceous in the United States is the Comanche series of the Texan region. Its outcrops extend from western Arkansas through southern Indian Territory to Denison and Preston, thence southward through Fort Worth, Austin, and

[1] SIR J. W. DAWSON, Trans. Roy. Soc. Canada, Vol. X, 1892, Sec. 4, pp. 81–82.

[2] Jahrb. der k. k. geol. Reichsanstalt, 1894, Bd. 44, p. 476.

[3] Erdgeschichte, Bd. 2, p. 391, 1883.

[4] Neues Jahrb. f. Mineral., Geol. und Paläont., Beilage Bd. 10, 1895, pp. 1–118.

San Antonio to the Rio Grande at Del Rio, covering large areas west of that line. It is known to underlie a large part of Mexico, extending as far west as Arivechi in Sonora. Small outlying areas occur in southern Arizona, at El Paso, Texas, in eastern New Mexico, in Oklahoma, and in southern Kansas. The stratigraphic details have been published mainly by Messrs. R. T. Hill, J. A. Taff, E. T. Dumble, W. F. Cummins, T. W. Vaughan, and C. S. Prosser.

The main features of Mr. Hill's classification of the deposits are as follows:

Comanche series	Washita	Shoal Creek limestone, Denison beds, Fort Worth limestone, Preston beds.
	Fredericksburg	Caprina (Edwards) limestone, Comanche Peak limestone, Walnut clays.
	Trinity	Paluxy sands, Glen Rose limestone and clays, Trinity sands.

This list gives the principal recognized subdivisions and indicates the lithologic character of the section in central Texas. Calcareous sediments of varying texture and composition largely predominate over all other kinds, thus contrasting strongly with the Shasta deposits. Considerable beds of sand are locally developed in the lower or Trinity division, and in the middle of the Washita clays and sandy layers usually predominate, but as a rule much more than half of the total thickness of the Comanche series consists of calcareous beds. Near the borders of the Comanche sea the limestones decrease in relative thickness or disappear entirely. At El Paso they form but a small proportion of the section, and in the Tucumcari region of New Mexico and in southern Kansas the rocks are all sandstones and clay shales. In the latter region the total thickness is only about 200 feet, and apparently the Washita division is the only one represented. In central Texas the entire series has a thickness of about 1500 feet, which increases southwestward, until

in northern Chihuahua it reaches 4000 feet, as estimated by Dr. C. A. White,[1] and still farther south very much greater thicknesses have been reported. Lithologically the Comanche series as a whole contrasts strongly with the Cretaceous rocks of all other parts of the United States, and indeed of North America, excepting Mexico, which is directly connected with the Texan area. Judging from the descriptions, lithologically similar Cretaceous rocks are developed to some extent in the northern part of South America and in southern Europe. We must go to these regions also, and especially to Portugal and Spain, as Mr. Hill has pointed out, to find closely related faunas.

Fossil plants have been obtained from two horizons, one in the Glen Rose beds of the Trinity division, about 250 feet above the base of the series, and the other in the so-called Cheyenne sandstone, at the base of the Cretaceous section in southern Kansas, but apparently within the Washita division. The plants from the lower horizon, which are directly associated with an abundant marine fauna, have been described by Professor Fontaine.[2] He recognized twenty-three distinct forms, consisting mainly of conifers and cycads, with a fern, an Equisetum, and a few forms of uncertain affinities. Of these seven are represented by identical and six by similar species in the Potomac, four occur in the Wealden of Europe, two in the Urgonian, with an additional one represented by a similar form, and six are peculiar to the Glen Rose. In discussing the age and affinities of these plants Professor Fontaine says: "The plants found at Glen Rose show, so far as can be judged from so imperfect a collection, that the Trinity flora finds its closest resemblance in the older portion of the lower Potomac. There is, however, this important difference: no trace of angiosperms, even the most archaic, has been found in the Texan region. We have only the four elements of the typical Jurassic flora. This, then, makes the Trinity flora somewhat older than that of the oldest Potomac. The absence of angiosperms and the presence of the forms that

[1] Am. Jour. Sci., 3d ser., Vol. XXXVIII, 1889, pp. 440–445.

[2] Proc. U. S. Nat. Museum, Vol. XVI, 1893, pp. 261–282.

are found indicate decidedly that the Trinity flora is not younger than the earliest stage of the Cretaceous. The number of plants found to be identical with certain of those of the oldest Potomac shows that there is little difference in the age of the two formations. The plant-bearing portion of the Trinity is somewhat older than the basal Potomac strata, but the difference in age cannot be great."

In this reasoning it seems to me that too much stress is laid on negative evidence, the absence of angiosperms. The present habits and distribution of plants do not warrant the assumption that a small collection containing only twenty-three species from a very limited area would necessarily include all the important types of plants living at the time they were entombed. The still more striking incompleteness of the Lower Cretaceous faunas will be discussed beyond. It will be remembered that the Kootanie flora and the plants from the Shasta, which were also compared with the Potomac flora, likewise showed the absence of dicotyledons and this was true even in the Horsetown beds which are known from their fauna and stratigraphic position to be far above the base of the Lower Cretaceous.

Among the plants from the Washita horizon in southern Kansas, Dr. Knowlton[1] has recognized seven species of which five are dicotyledons and two are conifers. The species identified had before been found only in the Dakota group in a flora usually assigned to the Cenomanian. It has been shown by Cragin,[2] however, that a part of the beds referred to the Dakota probably belongs to the Comanche series. At all events it is certain that the upper part of the Comanche approaches the Upper Cretaceous in character and it probably is not far from the horizon of the uppermost Potomac beds.

The vertebrates obtained from the Comanche series are few and mostly fragmentary. The descriptions and determinations of Williston,[3] Cragin,[4] and Cope[5] show the presence of fishes,

[1] In a paper by Mr. HILL, Am. Jour. Sci. 3d. ser. Vol. L, 1895, pp. 212–214.
[2] Am. Geologist, Vol. XVI, 1895, pp. 162–165.
[3] Kansas Uni. Quarterly, Vol. III, 1894, pp. 1–4.
[4] Colorado College Studies, Vol. V, 1895, pp. 69–73.
[5] Jour. Acad. Nat. Sci. Phila., Vol. IX, 1895, pp. 443–447.

turtles, crocodiles, and plesiosaurs but they have not furnished any very definite evidence as to the age of the beds. One of the fishes (described by Cope) came from the Glen Rose beds and another from an unknown locality in Texas. All the other vertebrates mentioned are from higher beds near Camp Supply, Oklahoma, and in southern Kansas. Fragmentary bones that are supposed to be dinosaurs but have not been definitely identified have been collected in the Trinity sands by Mr. Hill.

The invertebrate fossils are very numerous throughout almost all of the series above the basal Trinity sands, and constitute several distinct subfaunas though all are connected by species that pass from one zone to another and a few species range through a large part of the series. The species have been mostly described in various books and papers by Roemer, Giebel, Marcou, Shumard, Gabb, White, Hill, and Cragin. The revision of the invertebrate species with the description of new forms contained in recent collections on which I am at present engaged has not progressed far enough to enable me to give complete lists of the fossils of each zone but the general features of the fauna can be profitably discussed and some interesting comparisons can be made.

Mr. Hill's[1] reviews of the subfaunas of the Trinity division and of the Caprina limestone in the Fredericksburg division afford a basis for comparing these horizons with other Cretaceous beds. The list given for the Trinity (Glen Rose) includes about forty invertebrate species and this number will be considerably increased by the study of recent collections. The following characteristic forms, mostly from the same horizon as the Glen Rose plants, are the most important for our present purpose:

Ostrea franklini Coquand
Trigonia stolleyi Hill
Trigonia crenulata (Lam.) Roemer
Trigonia lerchi (Hill)
Trigonia n. sp.
Requienia cf. texana Roemer
Monopleura cf. marcida White
Monopleura cf. pinguiscula White
Cyprina sp.
Natica (Lunatia) pedernalis Roemer

[1] Proc. Biol. Soc. Washington, Vol. VIII, 1893, pp. 9–40, 97–108.

Tylostoma sp.
Glauconia branneri (Hill)
Glauconia cf. helvetica (Pictet and Renevier)
Glauconia cf. picteti Coquand
Nerinea sp.
Neumayria? ? walcotti Hill
Stoliczkaia justinae (Hill)

Excepting the ammonites and the last two species of Trigonia these forms are all very abundant in certain layers and give character to the fauna. The Ostrea is a simple form of little diagnostic value mentioned merely on account of its abundance. The Trigonias represent three groups, two of which, scabræ and quadratæ, are characteristic of the Cretaceous and the other, glabræ, occurs in both Jura and Lower Cretaceous. Requienia and Monopleura are not known outside of the Cretaceous and are found in the Urgonian and higher horizons of Portugal and other southern European countries.[1] *Natica piedernalis* is very like *N. simillinus* Choffat of the Urgonian of Portugal, and Choffat speaks of the great abundance of large Naticas in that horizon, though similar forms also occur in the Valanginian (Lower Neocomian) of the same region. The species of Glauconia are all represented by very similar southern European forms ranging from the Urgonian to the Aptian and perhaps higher. The two species of ammonites are not well enough known to be compared satisfactorily but their nearest relatives apparently are Lower Cretaceous species.

Several other forms have representative species in southern Europe but when the comparisons are all made the final result is not a definite correlation of the lowest fossiliferous beds of the Trinity with any particular horizon of the Lower Cretaceous, though the evidence is clear that it cannot be earlier than the Lower Cretaceous and that it probably is not the base of the Cretaceous.

[1] For stratigraphy and related species mentioned in this discussion see CHOFFAT Recueil de Monog. Stratig. sur le Système Crétacique du Portugal, Lisbonne, 1885 Recueil de Monog. palèont., etc., 1886.

PICTET et RENEVIER. Fossiles du Terrain Aptien de la Perte du Rhone.
PICTET et CAMPICHE. Fossiles du Terrain Crétacé des environs de Sainte Croix
DE LORIOL et DE LORIÈRÈ. Fossiles du Neocomien superieur de Utrillas.
COQUAND, Monographie paléontologique de l'etage Aptien de l'Espagne.

In the lower part of the Fredericksburg division the Naticas and Tylostomas, in part identical with those of the Trinity continue to play an important part. Here we find the first beds of Gryphaea belonging to the series of species that have often been grouped under the single name *Gryphaea pitcheri* Morton, but which are now separated into several species. These Gryphaeas occur in immense numbers at intervals to the top of the Comanche. Other ostreidae such as Exogyra and Alectryonia have a great development of individuals representing several species. Echinoids, belonging to the genera Enallaster, Hemiaster, Epiaster, Holaster, Holectypus Pseudodiadema, Cidaris, and a few others are also numerous and continue in greater or less abundance in the calcareous beds to top of the series. Among other common forms are Cyprimeria, with difficulty distinguishable from Upper Cretaceous species, several species of Nerinea, Aporrhaidae, etc. Three important species of ammonites, *Engonoceras piedernalis* (von Buch), *Schloenbachia acutocarinata* (Shumard) and *S. trinitensis* (Gabb) also occur.

The Caprina limestone constituting the upper part of the Fredericksburg divison has an interesting and remarkable fauna consisting largely of Requienia, Monopleura, Ichthyosarcolites and other Chamidae, with Radiolites or Sphærulites, Nerinea, many other gastropods, corals, etc. The general assemblage of forms is very much like that in the "Schrattenkalk" or "Caprotina limestone" of the Urgonian and the similarity extends to specific forms in many cases. There is also a more superficial resemblance to the Upper Cretaceous "Hippurite" limestone and it was partly this resemblance that caused Roemer and Heilprin[1] to refer the Comanche series to the Upper Cretaceous. While it would perhaps not be justifiable to call the Caprina limestone Urgonian (as defined by Choffat) or to say that they are exact homotaxial equivalents yet such a statement could not be very far from the truth. The two faunas resemble each other in so many particulars that there must have been free communication between the two areas and the conditions of

[1] Proc. Acad. Nat. Sci. Phila., 1890, pp. 445–469.

marine life must have been very nearly the same in both but as we do not know where the faunas originated nor the direction and rate of migration we can not determine the exact time relations of the deposits.

In the Washita division many of the elements of the Fredericksburg fauna continue either unchanged or but slightly modified. Among identical species that occur in the lower beds of the Washita *Exogyra texana*, *Turritella seriatim-granulata* and *Schloenbachia acuto-carinata* may be mentioned. The *Engonoceras* group[1] of ammonites also reappears in the upper part of the division. Ammonoids are more abundant in the lower Washita (Preston and Forth Worth beds) than in any other part of the Comanche series, though only a few types are represented. Besides those already mentioned, the large *Pachydiscus brazoensis* (Shumard) and *Hamites fremonti* Marcou are abundant, and there is a large development of the genus *Schloenbachia*, mostly of the type *S. inflata* (Sowerby). These forms together with the large *Turrilites brazoensis* Roemer, if occurring in Europe would probably be taken to indicate either uppermost Gault or lowest Cenomanian. A large development of littoral forms in the Denison beds of northern Texas, in the Tucumcari region of New Mexico, and in southern Kansas also gives the fauna a rather modern aspect. But its close relationship with the fauna of the underlying Fredericksburg division and the fact that the next succeeding fauna, that of the Timber Creek beds, contains species of Acanthoceras and other types resembling those that are characteristic of the Cenomanian in Europe tend to place it lower in the Cretaceous system. The uppermost beds of the Washita may possibly be as late as the Cenomanian, but the lower beds in which Schloenbachia is so abundant can hardly be more recent than the Gault. However this point may be decided, the most natural major plane of division in the Texan

[1] This group including *Ammonites piedernalis* van Buch, frequently spoken of as "Cretaceous Ceratites," or as "Buchiceras," in the broad sense in which it was originally defined, is considered characteristic of the southern European or Mediterranean Cretaceous.

Cretaceous is at the top of the Comanche series, and this plane seems to coincide very closely with the top of the Potomac and the top of the Shasta.

It has already been mentioned that the Cretaceous of part of the west coast of South America has some resemblance to the Comanche series, but little is published about the stratigraphy, and in describing the fossils few attempts have been made to indicate the different horizons, so that it is now impossible to make close comparisons. In Peru *Schloenbachia acuto-carinata*, and several large Naticas and Tylostomas, occur with a few other forms related to Comanche species. Similarly in Columbia *Ptychomya buchiana* (Karsten), *Exogyra boussingaulti* d'Orb. and several others have representatives in the Comanche. It has been assumed by some authors that these forms lived in the Pacific basin, and that they prove that the Pacific and Atlantic were connected during Lower Cretaceous time.

By independent comparisons with European Cretaceous faunas—principally northern European in one case and southern or Mediterranean in the other—aided by stratigraphic relation with overlying beds and by the evidence of the fossil plants we have reached the conclusion that the Shasta group and the Comanche series were essentially contemporaneous deposits. And yet their faunas are almost totally distinct. This separateness of the two faunas has frequently been mentioned by Dr. White[1] and the present writer,[2] but the real character of the differences has not been clearly stated. The differences are not dependent on fine discrimination of closely related species. On the contrary, whole genera and in some cases much higher groups that are abundant and characteristic in one area are entirely absent in the other. The following table will exhibit some of the more striking contrasts:

[1] Bull. U. S. Geol. Surv., No. 15, 1885, pp. 30–31; *ibid.*, No. 82, 1891, pp. 180–198.

[2] Bull. Geol. Soc. Am., Vol. IV, 1893, p. 254; JOUR. GEOL, Vol. III, 1895, pp. 858–861; Bull. U. S. Geol. Surv., No. 133, 1896, pp. 27, 31; DILLER and STANTON; Bull. Geo. Soc. Am., Vol. V, 1894, p. 462.

	Comanche.	Shasta.
Echinoids	Very abundant in several horizons	Presence barely indicated at one locality in the Knoxville
Terebratula	Abundant in two beds	Rarely represented
Rhynchonella	Absent	Locally abundant
Ostre dæ	Immensely abundant and represented by Ostrea, Gryphaea, Exogyra, and Alectryonia	Very scarce. A small Ostrea in the Knoxville and Exogyra at top of Horsetown
Aucella	Absent	Immensely abundant in the Knoxville
Trigonia	Common	Common, species not closely related
Rudistæ	Abundant in Caprina Limest.	Absent
Chamidæ	Abundant in Caprina Limest.	Absent
Cyprina	Very abundant	Rare
Protocardia	Large species abundant	One very small species of distinct type
Cyprimeria	Abundant	Absent
Naticidæ	Large species abundant	One or two small forms common
Glauconia	Abundant	Absent
Turritella	Abundant	Very rare
Nerinea	Abundant	Occurrence doubtful
Actæonella	Locally abundant	Rare
Lytoceras,	Absent	Abundant
Phylloceras	Absent	Abundant
Hoplites	Rare	Common
Ancyloceras	Absent	Common
Crioceras	Absent	Common
Hamites	Abundant in one bed	Absent
Pachydiscus	Abundant in one bed	Absent
Schloenbachia	Abundant in Fredericksburg and Washita divisions. Several species	One species. Rare at top of Horsetown
Engonoceras and related Ammonites	Common	Absent
Turrilites	Locally abundant	Absent
Belemnites	Absent	Common

The comparisons could be carried further, showing many other genera that are found in only one of the areas, and that those occurring in both are not represented by closely related species.

The two faunas are complements of each other, and both must be taken together to make up a really representative Lower Cretaceous fauna. Their differences agree in a general way with those that exist between the northern and southern

European Cretaceous, but there are some variations, such as the occurrence of Lytoceras and Phylloceras with boreal forms in the Shasta and their absence from the southern Comanche where they belong.

As to the causes of the sharp contrasts between the Cretaceous faunas of the Texan region and the Pacific Coast, reasons based on the distribution of the fossil plants and on the geographic relations of the deposits have already been given for denying any considerable influence to climate, that is, difference in temperature. Dr. White has argued for the existence of a long, narrow, continental land barrier between the two areas of deposition, and that is doubtless the only single cause that seems at all adequate to explain the facts. But how far south the barrier extended and whether its position was constant we do not know. It is known that the Comanche fauna at one time extended almost to the present Pacific Coast in northern Sonora, and there is evidence that the Pacific fauna may have extended as far east as Catorce in San Luis Potosi, but whether the two seas were really connected or what their exact relations were we can only hope to learn when the details of Mexican geology are fully studied. Besides the existence of a barrier, the depth and clearness of the sea and the character of the bottom also probably had considerable influence. These conditions would at least explain the abundance of echinoids in one case and their absence in the other. The Shasta beds give every evidence of rapid deposition near shore in shallow waters, with usually a muddy bottom, while a large part of the Comanche series was laid down in deeper waters, or at least little influenced by clastic deposits derived directly from the land. One other factor has suggested itself, though it is probably not of much weight, and that is that the gregarious mollusks, like Aucella and the Ostreidæ, actually monopolized the sea bottom where either became well established, so that there was not room for both in the same area.

The study of these two incomplete faunas should emphasize the danger in depending on the statistical method in correlating

formations — the method in which each specific name is treated as a unit and the relative affinities of different deposits or localities are determined automatically by counting the number of common species. Here there are two great series of beds, each with a fairly large fauna, and not very far separated geographically, and yet if directly compared they show no identical and very few related species. Again, these conditions are suggestive when considering a sudden complete change in successive faunas, such as is often seen. If the barrier between the Comanche and Shasta seas had been suddenly removed and the succeeding conditions had been favorable for the continuation of only one of the faunas, we would have had in one of the areas such a complete and sudden change in faunas in two successive beds that a long time interval might have been erroneously invoked to explain it.

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